

2. SOIL VAPOR PROBE

2.1 Introduction

Between April and September of 2001, 29 Type B vapor-sampling probes were installed in the SDA for the purpose of monitoring VOCs; C-14, present in CO₂; and tritium (H-3), present in water vapor. During FY 2003, quarterly vapor samples were taken and analyzed for VOCs, C-14, and tritium.

The *FY 2002 Summary Report* (Myers et al. 2003), hereinafter referred to as the *FY 2002 Summary Report*, contains descriptions of the probes and how they were installed. This report contains results from the FY 2003 samples and a discussion of the results as they relate to waste characterization, trends in VOC release, and validity of analysis methods and instruments. Probe locations and descriptions of the sample collection and analysis methods are repeated in this report for completeness.

2.1.1 Probe Locations

Sixteen of the Type B vapor probes were placed in the Series 743 sludge and depleted uranium (DU) focus areas (see Figures A-1 and A-2 in Appendix A) for monitoring VOC concentrations and some reducing/oxidizing gases. Thirteen probes for monitoring the radionuclide C-14 (as CO₂) were placed near SVR-12 and SVR-20 (see Figure A-3 in Appendix A). The four probes at SVR-20 are sampled also for tritium. See Table 2-1 for a list of probes and their depths, arranged by area.

Table 2-1. Type B vapor probe locations and port depths.

Probe	Probe Depth (ft)
Series 743 sludge focus area (volatile organic compounds)	
743-03-VP1	18.0
743-03-VP2	13.3
743-03-VP3	4.8
743-08-VP1	20.2
743-08-VP2	13.4
743-08-VP3	4.9
743-18-VP1	20.0
743-18-VP3	7.6
743-18-VP4	14.6
Depleted uranium focus area (volatile organic compounds)	
DU-08-VP2	15.8
DU-10-VP1	11.6
DU-10-VP2	10.0
DU-10-VP3	6.2
DU-14-VP1	16.1
DU-14-VP2	11.7

Table 2-1. (continued).

Probe	Probe Depth (ft)
DU-14-VP3	4.9
SVR-12 (C-14)	
SVR-12-1-VP1	11.7
SVR-12-1-VP2	7.6
SVR-12-1-VP3	2.7
SVR-12-2-VP1	11.9
SVR-12-2-VP2	7.7
SVR-12-2-VP3	2.6
SVR-12-3-VP1	11.8
SVR-12-3-VP2	7.6
SVR-12-3-VP3	2.5
SVR-20 (C-14)	
SVR-20-5-VP3	17.2

2.2 Volatile Organic Compounds

2.2.1 Sample Collection Method

Type B vapor probe VOC samples are collected inside of a glovebag in accordance with “Glovebag Supported Sample Acquisition from Type B Probes in the Subsurface Disposal Area” (TPR-1674). This technical procedure includes all aspects of acquiring VOC samples and handling the samples in the sample preparation facility. Inside the glovebag, samples are collected in either 1-L Tedlar bags or precleaned Summa canisters (250 mL or 6 L).

The Tedlar bags are filled by connecting them to a port on the inside of a vacuum chamber box that is connected to the vapor probe sample port. Vacuum is then applied to the vacuum chamber box, allowing the Tedlar bag to fill with soil vapor. Summa canisters are filled by removing the vacuum chamber box and connecting the Summa canister directly to the vapor-port line inside the glovebag. The Summa canister is preevacuated so that, when the valve on the canister is opened, the vapor sample is drawn inside until the gauge reaches zero or until the preset time in the procedure (TPR-1674) has elapsed, whichever occurs first.

2.2.2 Sample Schedule

The original sampling schedule, as outlined in the *Field Sampling Plan* (Salomon 2003), called for quarterly sampling until a baseline was established. However, a baseline had not been established, according to the *FY 2002 Summary Report* (Myers et al. 2003), and it was recommended that quarterly sampling continue at least through FY 2003. Therefore, samples were collected from selected probes in all four quarters of FY 2003.

2.2.3 Probe Functionality

Since installation, only eight of the 16 vapor probes installed in the Series 743 sludge and DU focus areas have yielded samples on a consistent basis. During the second quarter of FY 2003, only seven probes yielded samples, as Probe 743-18-VP4 did not yield a sample for the first time. During the last quarter, however, 13 of the 16 probes yielded samples. This included five probes that had never yielded a sample before this time. The historical functionality of the probes is shown in Figure 2-1. The ability to get samples from five previously unyielding probes is attributed to modifications to the glovebox and replacement of the line at the vacuum pump.

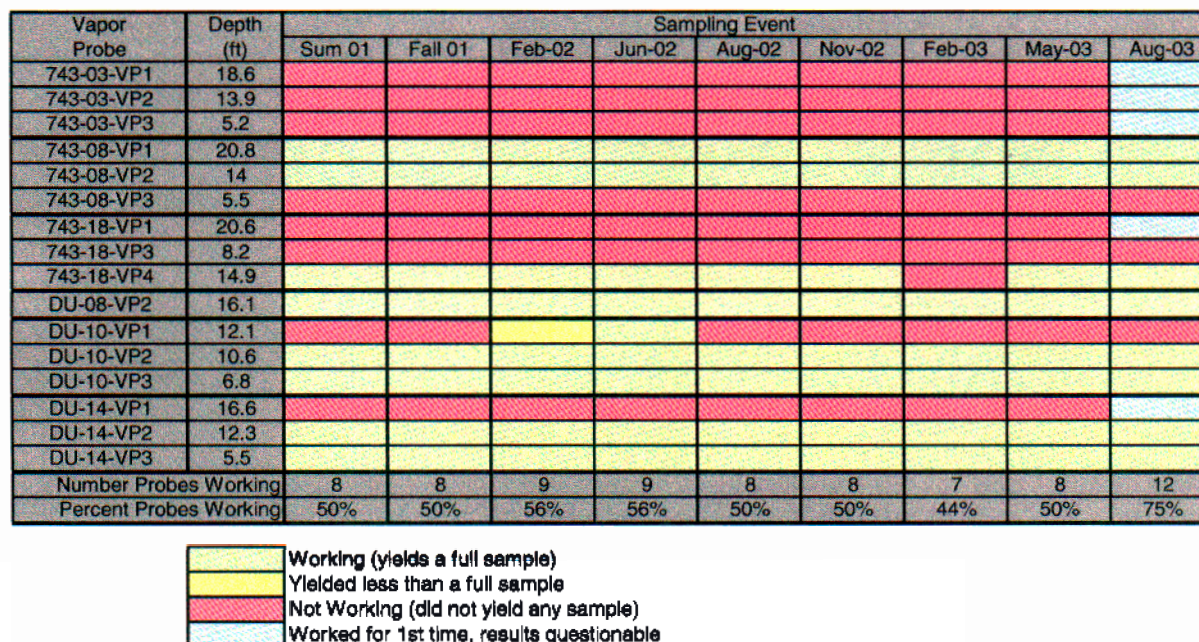


Figure 2-1. Functionality summary for the Subsurface Disposal Area vapor probes.

2.2.4 Analysis Methods

The Type B vapor probe samples were analyzed with an Innova Model 1314 photoacoustic multigas analyzer for the VOCs shown in Table 2-2. The table also contains the concentration range of the filters in the Innova analyzer. Since these are the only filters in the instrument, only the VOCs shown in Table 2-2 are measured.

Table 2-2. Volatile organic compounds analyzed by the Innova photoacoustic multigas analyzer and the filter concentration ranges.

Analyte	Formula	Optical Filter Range (ppmv)
Carbon tetrachloride	CCl ₄	6 to 100,000
Chloroform	CHCl ₃	1 to 10,000
Trichloroethene	C ₂ HCl ₃	0.09 to 9,000
Tetrachloroethene	C ₂ Cl ₄	0.3 to 10,000
1,1,1-trichloroethane	C ₂ H ₃ Cl ₃	0.04 to 4,000

The measurement principle of the Innova analyzer is based on the photoacoustic infrared detection method. The instrument can measure almost any vapor that absorbs infrared light (e.g., most chlorinated solvents). The Innova analyzer compensates any measurement for temperature fluctuations, water-vapor interference, and interferences from other gases or vapors known to be present.

In accordance with the *Field Sampling Plan* (Salomon 2003), some of the field duplicate samples were collected in Summa canisters and analyzed using standard laboratory gas chromatography/mass spectrometry (GC/MS) methods as an accuracy check on the Innova results. After the first quarter of FY 2003, the duplicate samples were analyzed by the INEEL Environmental Chemistry Laboratory (ECL) using modified U.S. Environmental Protection Agency Method TO-14 with a target analyte list of 29 VOCs, including the five VOCs analyzed by the Innova analyzer. The on-Site lab (INEEL ECL) was chosen because it performs VOC analysis for the Waste Isolation Pilot Plant 3,100 m³ Program and is considered an outstanding technical resource. Off-Site labs were used for VOC analysis for the first quarter of FY 2003. However, use of the off-Site labs was discontinued after the first quarter because the results were considered unusable (Myers et al. 2003).

2.2.5 Results

The Type B vapor probe VOC sampling results and duplicate analyses for the four quarters of FY 2003 are shown in Table 2-3 (only the five VOCs analyzed by the Innova analyzer are listed). Collocated duplicate samples collected in Summa canisters were analyzed for several other VOCs in addition to the ones in Table 2-2. However, only six other VOCs were detected in those samples, and of those, only three were detected on a semiconsistent basis. The following list includes those three VOCs, their maximum measured concentrations, and the probe where they were measured:

- Methylene chloride, 700 ppmv, 743-08-VP1
- Chloromethane; 1,500 ppmv; 743-08-VP2
- 1,1,2-trichloro-1,2,2-trifluoroethane (F-113), 220 ppmv, 743-08-VP2.

Table 2-3. Vapor probe sampling results for the four quarterly sampling rounds of Fiscal Year 2003.

Probe	Probe Depth (ft)	Container	Carbon Tetrachloride (ppmv)	Chloroform (ppmv)	1,1,1-Trichloroethane (ppmv)	Trichloroethene (ppmv)	Tetrachloroethene (ppmv)
First Quarter—Fiscal Year 2003							
743-08-VP1	20.8	TB	44,640	22,160	1,548	7,081	ND
743-08-VP2	14.0	TB	54,750	15,810	1,475	3,070	33
743-08-VP2	14.0	Summa 6 L ^a	42,000	19,000	<3,200	4,900	<3,200
743-08-VP2	14.0	Summa 6 L ^a	61,000	22,000	1,900	5,300	<390
743-08-VP2	14.0	TB	54,460	15,300	1,459	2,944	33
743-18-VP4	14.9	TB	10,760	1,670	374	2,074	66
DU-08-VP2	16.1	TB	12,670	8,185	3,793	8,863	1,963
DU-10-VP2	10.6	TB	6,218	1,885	2,218	4,162	2,070
DU-10-VP3	6.8	TB	10,190	1,568	1,880	2,866	2,162
DU-14-VP2	12.3	TB	7,298	5,113	1,649	10,240	ND
DU-14-VP3	5.5	TB	840	571	449	1,016	546

Table 2-3. (continued).

Probe	Probe Depth (ft)	Container	Carbon Tetrachloride (ppmv)	Chloroform (ppmv)	1,1,1-Trichloroethane (ppmv)	Trichloroethene (ppmv)	Tetrachloroethene (ppmv)
Second Quarter—Fiscal Year 2003							
743-08-VP1	20.8	TB	37,860	19,700	1,359	5,494	50
743-08-VP2	14.0	Summa 250 mL ^b	45,000	11,000	1,200	2,900	ND
743-08-VP2	14.0	Summa 250 mL ^b	47,000	11,000	1,300	3,000	ND
743-08-VP2	14.0	TB	42,590	13,860	1,236	2,451	38
DU-08-VP2	16.1	TB	11,120	7,516	3,484	7,618	2,219
DU-10-VP2	10.6	TB	3,976	1,360	1,570	3,000	1,694
DU-10-VP3	6.8	TB	7,077	1,150	1,448	2,220	1,700
DU-14-VP2	12.3	TB	5,902	4,322	1,433	8,400	364
DU-14-VP3	5.5	TB	891	564	449	953	493
Third Quarter—Fiscal Year 2003							
743-08-VP1	20.8	TB	45,360	20,670	1,585	8,494	ND
743-08-VP1	20.8	Summa 250 mL ^b	29,000	12,000	1,100 J	9,700	ND
743-08-VP2	14.0	TB	45,700	14,340	1,308	3,100	48
743-08-VP2	14.0	TB	46,460	13,950	1,306	3,194	41
743-18-VP4	14.9	TB	7,567	1,218	249	1,467	58
DU-08-VP2	16.1	TB	10,170	6,826	3,167	6,096	,664
DU-10-VP2	10.6	TB	3,657	1,499	1,471	2,656	,374
DU-10-VP2	10.6	Summa 250 mL ^b	2,400	540	1,100	2,100	750
DU-10-VP3	6.8	TB	7,069	1,194	1,568	2,252	1,593
DU-14-VP2	12.3	TB	5,833	4,270	1,325	7,935	209
DU-14-VP3	5.5	TB	1,108	793	562	1,257	552
Fourth Quarter—Fiscal Year 2003							
743-03-VP1	18.6	TB	169	35	9	47	14
743-03-VP2	13.9	TB	82	20	5	17	8
743-03-VP3	5.2	TB	1,011	246	50	26	-2
743-08-VP1	20.8	TB	50,370	21,670	1,701	9,116	ND
743-08-VP1	20.8	Summa 250 mL ^b	26,000	9,600	960	7,600	ND
743-08-VP2	14.0	TB	55,080	15,600	1,488	3,607	54
743-08-VP2	14.0	TB	54,680	15,090	1,462	3,585	39
743-18-VP1	20.6	TB	117	45	14	47	25
743-18-VP4	14.9	TB	8,261	1,116	270	1,459	33
DU-08-VP2	16.1	TB	10,140	6,722	3,203	5,851	1,364
DU-10-VP2	10.6	TB	5,110	2,100	1,950	3,258	1,593
DU-10-VP2	10.6	Summa 250 mL ^b	2,800	650	1,400	2,400	900
DU-10-VP3	6.8	TB	9,793	1,682	2,211	3,129	2,274
DU-14-VP1	16.6	TB	221	133	71	174	93

Table 2-3. (continued).

Probe	Probe Depth (ft)	Container	Carbon Tetrachloride (ppmv)	Chloroform (ppmv)	1,1,1-Trichloroethane (ppmv)	Trichloroethene (ppmv)	Tetrachloroethene (ppmv)
DU-14-VP2	12.3	TB	5,301	3,934	1,186	7,428	184
DU-14-VP3	5.5	TB	930	731	461	1,146	457

Sample was obtained from this port for the first time

a. Summa 6-L canisters analyzed by gas chromatography/mass spectrometry at Southwest Laboratory of Oklahoma

b. Summa 250-mL canisters analyzed by gas chromatography/mass spectrometry at Idaho National Engineering and Environmental Laboratory Environmental Chemistry Laboratory

J = estimated value

ND = nondetect

TB = Tedlar bag (These samples were analyzed with the Innova instrument.)

For completeness, Table 2-4 includes FY 2002 results as well, but only for analyses using the Innova. If duplicate or split samples were taken, only the first (regular) sample result is shown.

Table 2-4. Subsurface Disposal Area vapor probe sampling results using the Innova analyzer.

Probe	Probe Depth (ft)	Date Sampled	Carbon Tetrachloride (ppmv)	Chloroform (ppmv)	1,1,1-Trichloroethane (ppmv)	Trichloroethene (ppmv)	Tetrachloroethene (ppmv)
743-03-VP1	19.0	8/4/03	169	35	9	47	14
743-03-VP2	14.0	8/4/03	82	20	5	17	8
743-03-VP3	5.0	8/4/03	1,011	246	50	26	-2
743-08-VP1	21.0	2/11/02	30,233	22,339 ^a	974	3,178	470
		6/10/02	57,466	22,119	1,881	9,723	-800 ^b
		8/20/02	56,140	22,120	1,818	10,080	-856 ^b
		11/20/02	44,640	22,160	1,550	7,080	-192 ^b
		2/18/03	37,860	19,700	1,359	5,494	50
		5/21/03	45,360	20,670	1,585	8,494	-490 ^b
		8/6/03	50,370	21,670	1,701	9,116	-599
		2/11/02	36,277	15,405	918	1,451	181
743-08-VP2	14.0	6/12/02	54,231	13,618	1,405	3,106	53
		8/27/02	62,171 ^a	15,372	1,559	3,405	78
		11/20/02	54,800	15,800	1,480	3,070	33
		2/18/03	42,590	13,860	1,236	2,451	38
		5/20/03	45,700	14,340	1,308	3,100	48
		8/6/03	55,080	15,600	1,488	3,607	54
743-18-VP1	21.0	8/4/03	117	45	14	47	25
743-18-VP4	15.0	2/12/02	8,616	1,385	231	1,358	218
		6/12/02	8,904	1,353	291	1,621	68
		8/15/02	11,750	1,490	387	2,133	32
		11/18/02	10,800	1,670	374	2,070	66
		5/20/03	7,567	1,218	249	1,467	58
DU-08-VP2	16.0	8/4/03	8,261	1,116	270	1,459	33
		2/13/02	11,359	8,559	2,760	4,957	924
		6/11/02	12,478	8,571	3,479	6,626	2,331
		8/15/02	12,750	8,331	3,618	7,663	2,203
		11/18/02	12,700	8,190	3,790 ^a	8,860	1,960
		2/17/03	11,120	7,516	3,484	7,618	2,219

Table 2-4. (continued).

Probe	Probe Depth (ft)	Date Sampled	Carbon Tetrachloride (ppmv)	Chloroform (ppmv)	1,1,1-Trichloroethane (ppmv)	Trichloroethene (ppmv)	Tetrachloroethene (ppmv)
DU-10-VP1	12.0	5/21/03	10,170	6,826	3,167	6,096	1,664
		8/4/03	10,140	6,722	3,203	5,851	1,364
		2/12/02	941	434	136	360	136
		6/11/02	1,053	579	271	651	187
DU-10-VP2	11.0	2/12/02	7,026	1,942	1,610	3,187	1,648
		6/10/02	6,014	1,995	1,729	3,408	1,668
		8/20/02	7,896	2,701	2,387	4,266	2,129
		11/18/02	6,220	1,890	2,220	4,160	2,070
DU-10-VP3	6.8	2/17/03	3,976	1,360	1,570	3,000	1,694
		5/21/03	3,657	1,499	1,471	2,656	1,374
		8/6/03	5,110	2,100	1,950	3,258	1,593
		2/12/02	11,381	1,719	1,310	2,098	1,449
		6/11/02	14,051	1,904	1,992	3,206	2,205
		8/15/02	17,360	2,485	2,640	4,259	2,942 ^a
		11/18/02	10,200	1,570	1,880	2,870	2,160
		2/17/03	7,077	1,150	1,448	2,220	1,700
		5/21/03	7,069	1,194	1,568	2,252	1,593
		8/6/03	9,793	1,682	2,211	3,129	2,274
		8/4/03	221	133	71	174	93
		2/12/02	6,083	4,515	1,146	7,263	724
DU-14-VP1	17.0	6/11/02	6,323	4,524	1,360	7,884	365
		8/15/02	7,453	5,212	1,528	10,090	-62 ^b
		11/18/02	7,300	5,110	1,650	10,200 ^a	-52 ^b
		2/18/03	5,902	4,322	1,433	8,400	364
DU-14-VP2	12.0	5/21/03	5,833	4,270	1,325	7,935	209
		8/4/03	5,301	3,934	1,186	7,428	184
		2/12/02	1,081	541	312	710	381
		6/11/02	1,558	1,029	694	1,612	810
		8/15/02	2,062	1,466	902	2,050	986
		11/18/02	840	571	449	1,020	546
		2/18/03	891	564	449	953	493
		5/21/03	1,108	793	562	1,257	552
		8/4/03	930	731	461	1,146	457
		2/12/02	1,081	541	312	710	381

a. Maximum measured concentration

b. Negative results are considered undetected

2.2.6 Discussion of Results

The FY 2004 Type B vapor probe VOC sampling results contain a large amount of useful information to help characterize the VOC source. This section points out and discusses the limitations and significance of the results.

2.2.6.1 Accuracy. Each quarter beginning with the third quarter of 2002, duplicate samples have been taken from at least one and sometimes two probes and sent to a laboratory for GC/MS analysis as a check on the accuracy of the Innova results. Two laboratories have been used in the past for VOC analysis: the INEEL ECL and the Southwest Laboratory of Oklahoma (SWLO). The third-quarter

FY 2002 samples were sent to ECL, and the GC/MS results were in good agreement with the Innova results. Duplicate samples from the fourth quarter of FY 2002 and the first quarter of FY 2003 were sent to SWLO. Because of problems with dilution and holding times and other questions regarding the SWLO data, the project decided that ECL would do all future GC/MS analysis of duplicate VOC samples.

If only the ECL results are considered, the agreement between the Innova analyses and the GC/MS analyses was good up until the last two quarters of FY 2003. Results from the last two quarters of FY 2003 show significant differences between the two, and the difference is becoming larger. Figures 2-2 and 2-3 show comparisons of carbon tetrachloride results from the Innova and the GC/MS for Clusters 743-08 and DU-10, respectively. Where duplicate or split samples were analyzed by the same instrument, the average values were plotted. In third quarter FY 2002, collocated duplicate sample results from both the Innova and GC/MS were in very good agreement. Innova and GC/MS results from Probe 743-08-VP1 were within 3%, and results from Probe DU-10-VP2 were within 4%. Then, samples from second quarter FY 2003 from Probe 743-08-VP2 were sent to the INEEL ECL, and the results were still in good agreement (within 8%) with the Innova results. However, third- and fourth-quarter FY 2003 duplicate samples from both Probes 743-08-VP1 and DU-10-VP2, analyzed by both the Innova and GC/MS, were much different from each other. In addition, the results appear to be diverging with time, with the Innova results increasing and the GC/MS results decreasing. The percent difference for the third to the fourth quarters was 36% and 48%, respectively, for Probe 743-08-VP1, and 34% and 45% for Probe DU-10-VP2. The trend is similar for other VOCs.

Considering the differences between the Innova and GC/MS results, the two possible scenarios are either (1) the Innova data or the INEEL ECL data are incorrect or (2) they both are incorrect. This issue currently is being investigated to determine the cause for the discrepancy. A plan will be prepared to identify and correct the problem. The results are discussed in the remainder this section in light of these data uncertainties that became apparent during the last quarters of FY 2003.

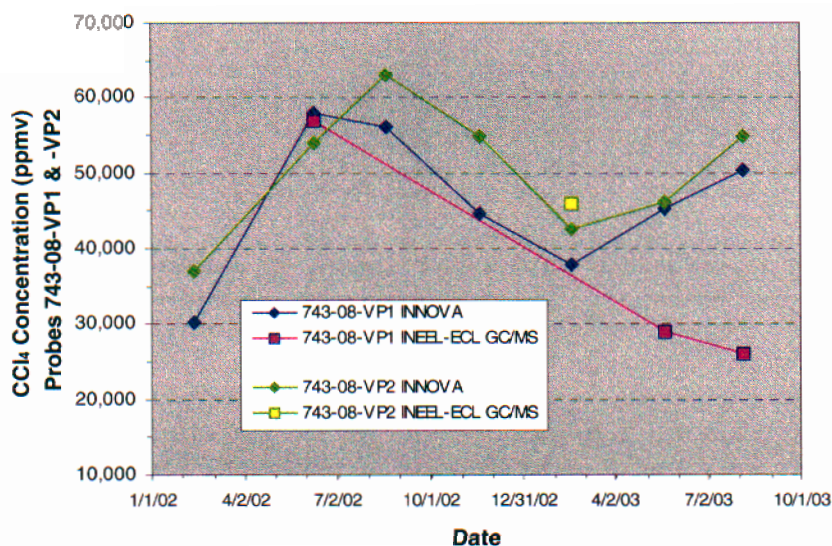


Figure 2-2. Comparison of Innova and gas chromatography/mass spectrometry results for duplicate samples taken from Probes 743-08-VP1 and 743-08-VP2.

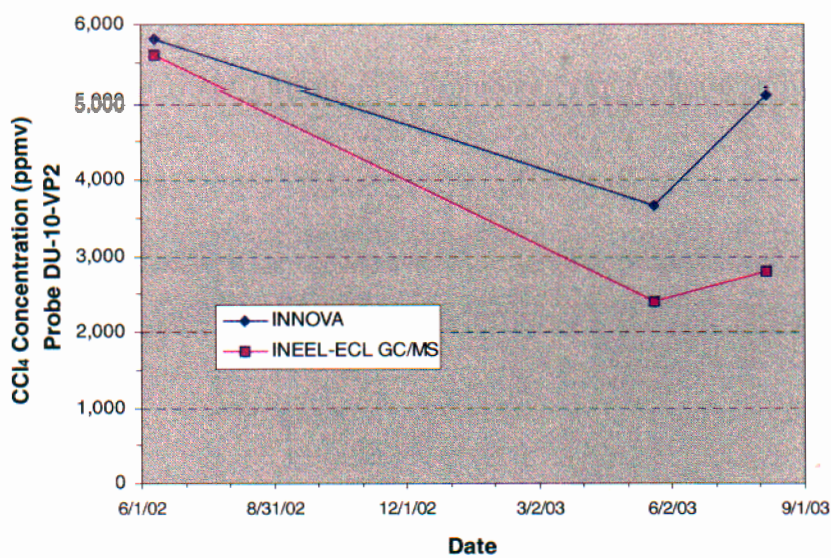


Figure 2-3. Comparison of Innova and gas chromatography/mass spectrometry results for duplicate samples taken from Probes 743-08-VP1 and 743-08-VP2.

2.2.6.2 Spatial and Temporal Trends. In FY 2003, the highest concentrations of carbon tetrachloride and chloroform were measured at Cluster 743-08. The highest concentrations of 1,1,1-trichloroethane (TCA), trichloroethene (TCE), and tetrachloroethene (PCE) were measured in the DU focus area at Clusters DU-08, DU-14, and DU-10, respectively. The locations of the maximums in FY 2003 are consistent with the previous year. Overall, there was not a significant drop in maximum concentrations, with the possible exception of carbon tetrachloride dropping from a maximum of 62,171 to 55,080 ppmv at Probe 743-08-VP2. Since the maximum concentrations occurred during the first quarter of FY 2003, this conclusion is not likely to be affected by the uncertainty in the last two quarters of data.

The fact that carbon tetrachloride concentrations are higher in the Series 743 sludge focus area than in the DU focus area is significant in that it validates key information and assumptions used by Miller and Varvel (2001) to determine the mass of VOCs, specifically carbon tetrachloride, buried in the SDA. Miller and Varvel (2001) divided Series 743 sludge drums into two populations: (1) "903-era" drums that were filled between February 1967 and August 1968 when a backlog of sludge-filled drums stored at the Rocky Flats Plant 903 Storage Area was processed along with smaller amounts of waste generated from routine operations during that period and (2) "non-903-era" drums that resulted from processing waste generated by routine operations before and after the 903-era drum processing. Miller and Varvel (2001) estimated that the 903-era drums contained a much higher percentage of carbon tetrachloride than the non-903-era drums.

The Series 743 sludge focus area contains 903-era drums exclusively. The DU focus area, on the other hand, contains almost exclusively non-903-era drums. Table 2-5 shows the ratio of the average carbon tetrachloride concentration to the average concentration of the other VOCs in both the Series 743 sludge and DU focus areas. The numbers were determined by calculating the average concentration of each VOC at each probe using all the data (FY 2002 and FY 2003). The ratios of carbon tetrachloride to the other VOCs were then calculated for both the Series 743 and DU focus areas based on the average

Table 2-5. Comparison of the average ratio of carbon tetrachloride concentrations to other volatile organic compounds in the Series 743 sludge and depleted uranium focus areas.

Volatile Organic Compound Ratio	Series 743 sludge Focus Area	Depleted Uranium Focus Area
Carbon tetrachloride/ chloroform	4	3
Carbon tetrachloride/ 1,1,1-trichloroethane	33	4
Carbon tetrachloride/ trichloroethene	10	2
Carbon tetrachloride/ tetrachloroethene	340	7

concentrations. The ratio of carbon tetrachloride to chloroform in both the Series 743 sludge and DU focus areas is nearly the same (4 and 3). This is because the chloroform is produced by degradation of carbon tetrachloride and not a component of sludge. The ratio of carbon tetrachloride to the other VOCs, however, is dramatically different between the two areas, which is consistent with *Reconstructing the Past Disposal of 743-Series Waste in the Subsurface Disposal Area for Operable Unit 7-08, Organic Contamination in the Vadose Zone* (Miller and Varvel 2001). This conclusion also is not affected by the uncertainty in the data during the last two quarters of FY 2003.

As for temporal differences in concentration, FY 2003 results appear to be slightly lower overall from FY 2002 concentrations based on the Innova results being accurate. For example, at the eight probe locations that have consistently yielded a sample, the average concentrations in FY 2003 were less than the average FY 2002 concentrations in 33 of the 40 cases (8 probes \times 5 VOCs = 40 cases) although some changes were very small. If, however, the GC/MS results are more accurate than the Innova results, the FY 2003 results are definitely lower overall than the FY 2003 results.

Figures 2-4 and 2-5 show the time history of carbon tetrachloride at each of the ports with more than one data point. (In Figures 2-4 and 2-5, where duplicate or multiple samples were taken during a single sampling event, the concentration of the original sample was used.) The August 2003 (fourth quarter) data from the five probes that had not previously been sampled are not included because of data-validity questions that are discussed in Section 2.2.6.4. The data are plotted on two different figures because of the difference in the magnitude of the results. At Probes 743-08-VP1 and 743-08-VP2, the concentrations appear to rise and fall seasonally with lows occurring in the colder months and highs during the warmer months (see Figure 2-4). This is especially true if the Innova data from the last two quarters of FY 2003 are accurate. It is less so if the GC/MS data are more accurate. The fact that concentrations increase during the warmer months is consistent with the vapor pressure dependence on temperature and subsequent volatilization or release of VOCs (i.e., volatilization increases as soil or waste temperatures increase). If this is indeed a seasonal trend, it will require a longer period to confirm and understand the phenomenon and to determine overall trends (increase or decrease and rate) in the release. At the other locations (see Figure 2-5), any trends, seasonal or otherwise, are more difficult to detect. Some probes show a seasonal trend similar to the 743-08 probes, and others show a slight overall decrease in concentration.

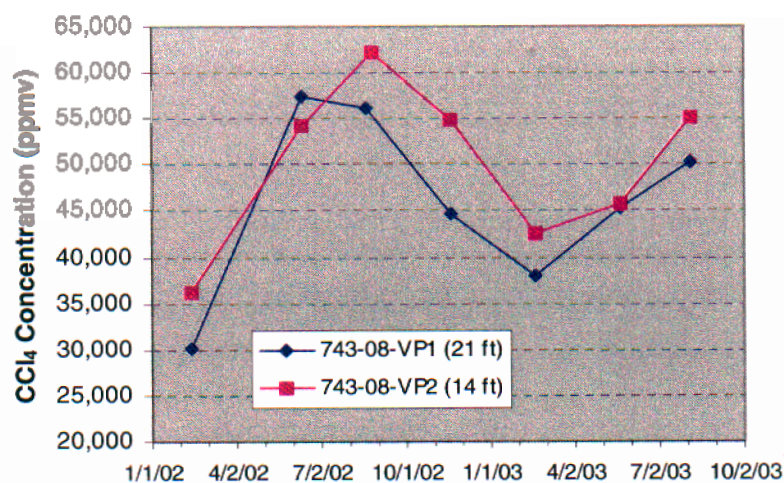


Figure 2-4. Carbon tetrachloride subsurface vapor concentrations at vapor probe Cluster 743-08.

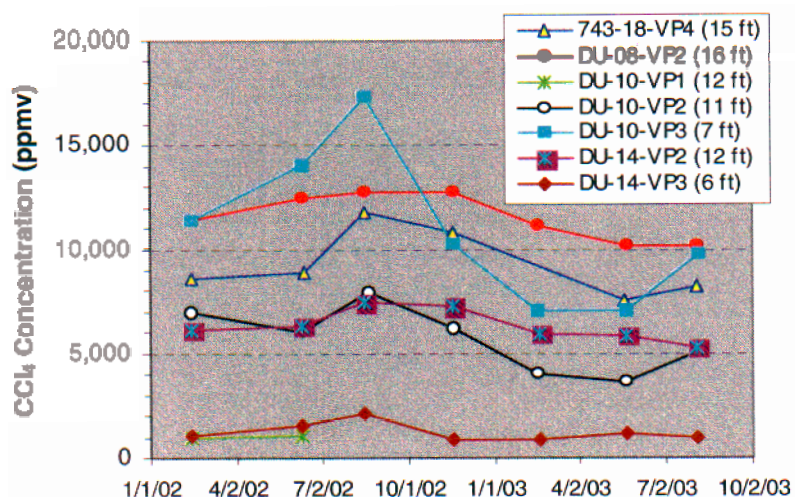


Figure 2-5. Carbon tetrachloride subsurface vapor concentrations at vapor probe Clusters 743-18, DU-08, DU-10, and DU-14.

There is also another interesting aspect to the data from Probes 743-08-VP1 and 743-08-VP2. Figure 2-4 shows the carbon tetrachloride data at Probe 743-08-VP2 lag behind the data at Probe-743-08-VP1 at least until the last two quarters of FY 2003. This does not correspond to the theory that temperature influences results, since the more shallow Probe 743-08-VP2 would respond faster to changes in surface temperature. However, if the source is stronger at the deeper probe (743-08-VP1) and the concentrations at the more shallow probe (743-08-VP2) respond to changes in release at the deeper probe (743-08-VP1), then the theory makes more sense. This will be examined further as more data are available to determine the cause of the apparent time lag.

Figures 2-6 and 2-7 show monitoring results for chloroform for the same eight ports that have consistently yielded a sample. In Figures 2-6 and 2-7, where duplicate or multiple samples were taken during a single sampling event, the concentration of the original sample was used. Again, the data are shown on two different scales because of the difference in the magnitude of the results. It makes sense that the maximum chloroform concentration is grouped with the maximum carbon tetrachloride concentration, given there was virtually no chloroform disposed of and the likely source of the chloroform is degradation of carbon tetrachloride. For chloroform, however, the same supposed seasonal trend is not as evident. This could be caused by the fact that chloroform is produced by degradation at a constant rate or that chloroform has a lower vapor pressure and is less affected by changes in temperature.

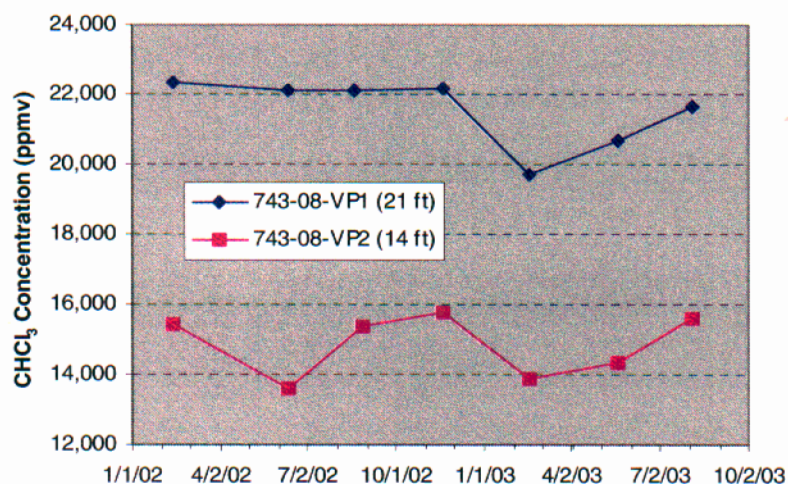


Figure 2-6. Chloroform subsurface vapor concentrations at vapor probe Cluster 743-08.

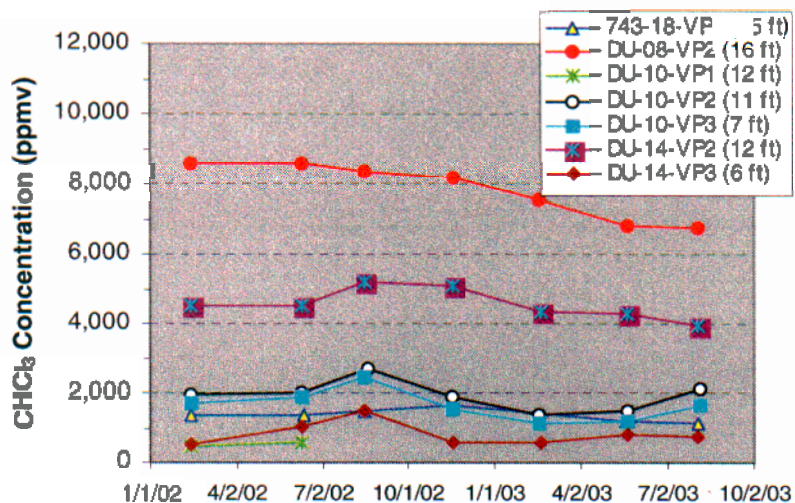


Figure 2-7. Chloroform subsurface vapor concentrations at vapor probe Clusters 743-18, DU-08, DU-10, and DU-14.

Figures 2-8 through 2-10 show the time history of concentration at the same eight ports for the other three VOCs: TCA, TCE, and PCE. In Figures 2-8 through 2-10, where duplicate or multiple samples were taken during a single sampling event, the concentration of the original sample was used. For TCA, TCE, and PCE, a seasonal trend is more evident than for chloroform. This points to temperature being an important influence on the release rate. In any case, it does not appear that concentrations are dramatically increasing or decreasing with time. Again, a seasonal trend is more likely if the Innova data for the last two quarters of FY 2003 are more accurate than the GC/MS data.

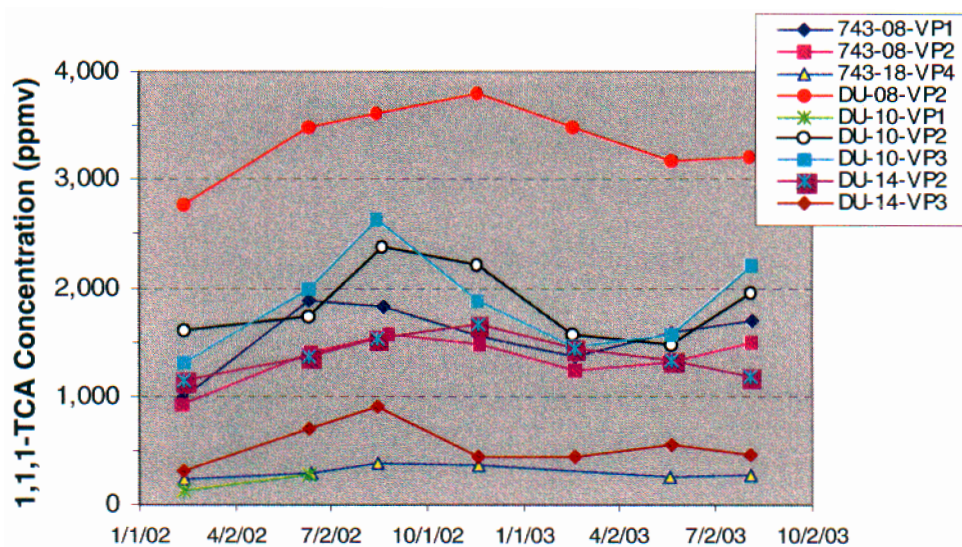


Figure 2-8. 1,1,1-trichloroethane subsurface vapor concentrations for probes consistently yielding a sample.

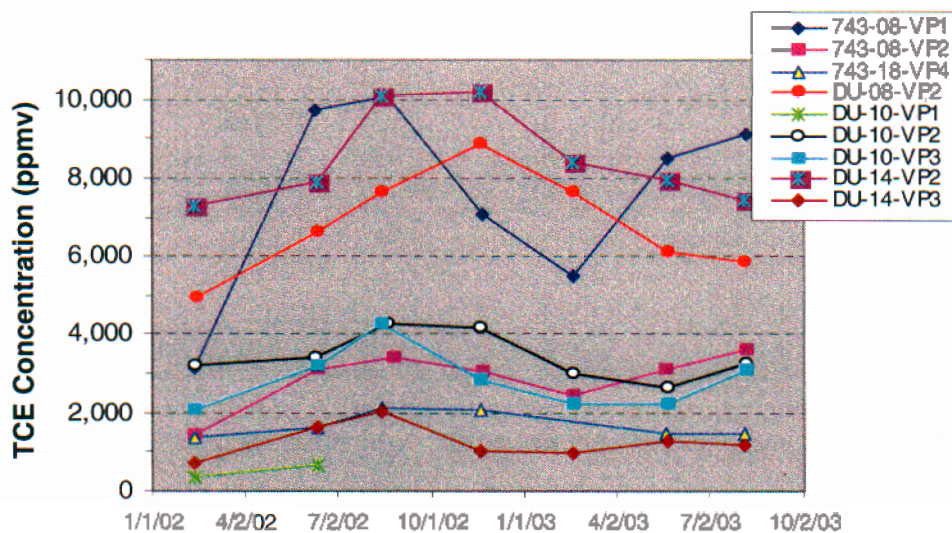


Figure 2-9. Trichloroethene subsurface vapor concentrations for probes consistently yielding a sample.

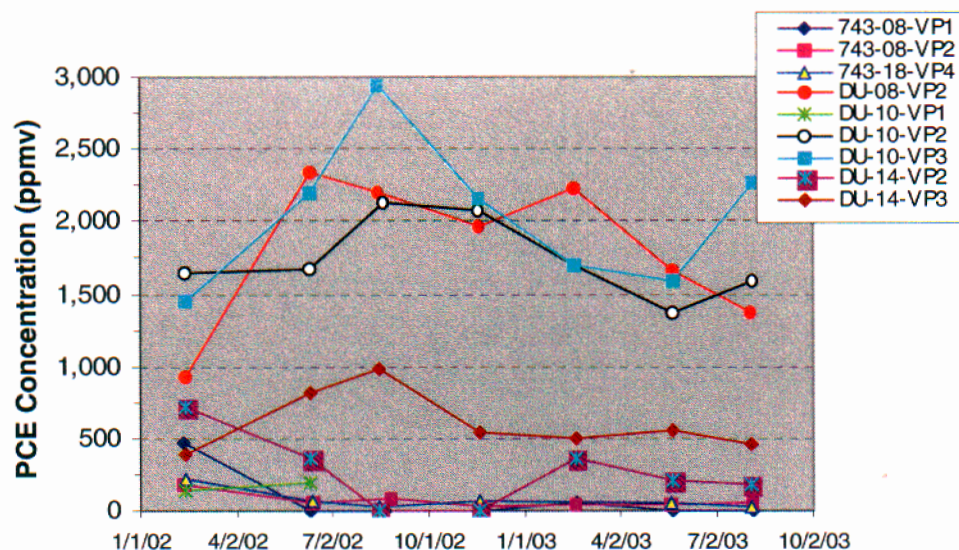


Figure 2-10. Tetrachloroethene subsurface vapor concentrations for probes consistently yielding a sample.

2.2.6.3 Indications of Residual Nonaqueous-Phase Liquid Volatile Organic Compounds in the Waste Zone. The high VOC concentrations in the waste, specifically Cluster 743-08, indicate that nonaqueous-phase liquid VOCs remain in the Series 743 sludge. Table 2-6 compares the maximum measured VOC concentrations to that of pure component equilibrium vapor concentrations and the equilibrium vapor concentrations at the estimated mole fractions in the original Series 743 sludge mixture. The vapor concentrations of the mixture are lower because the partial vapor pressures in the mixture are lower than for a pure component.

Table 2-6. Volatile organic compound pure component equilibrium vapor concentrations and equilibrium vapor concentrations at estimated mole fractions of original Series 743 sludge mixture (temperature assumed 10°C).

Volatile Organic Compound	Probe	Maximum Measured Gas Concentration (ppmv)	Pure Component Equilibrium Gas Concentration (ppmv)	Estimated Mole Fraction of Volatile Organic Compounds in Original Series 743 Sludge Mixture ^a	Equilibrium Gas Concentration of Volatile Organic Compounds in Series 743 Sludge Mixture (ppmv)
Carbon tetrachloride	743-08-VP2	62,171	71,000	0.65	46,000
Chloroform	743-08-VP1	22,339	129,000	NA ^b	NA ^b
1,1,1-trichloroethane	DU-08-VP2	3,790	81,000	0.07	6,000
Trichloroethene	743-08-VP1	10,200	48,000	0.08	3,900
Tetrachloroethene	DU-10-VP3	2,942	10,000	0.07	750

Boldface type indicates a maximum measured concentration greater than the equilibrium concentration of the mixture.

a. Balance of mole fraction made up of Texaco Regal Oil

b. Chloroform not a component of Series 743 sludge

The maximum measured carbon tetrachloride, TCE, and PCE concentrations are greater than the estimated equilibrium vapor concentrations of the mixture. The maximum measured concentration for carbon tetrachloride is almost equivalent to the equilibrium vapor concentration of the pure component. The maximum TCA concentration approaches the value for the mixture. If it is assumed that the mole fractions of the mixture after 30+ years of burial have not changed from the original mixture, which is appropriate for a rough comparison, the maximum measured vapor concentrations indicate that nonaqueous-phase liquid VOCs are still present in the sludge. This conclusion is not affected by the uncertainty in the data for the last two quarters of FY 2003.

2.2.6.4 Results from Previously Plugged Ports. Before the last quarter of FY 2003, eight of the 16 vapor probes had never yielded a sample (i.e., were plugged). Then, in the last quarter of FY 2003, samples were obtained from five of those eight previously plugged probes. Three of these probes are at Cluster 743-03, and the other two probes are 743-18-VP1 and DU-14-VP1. The results from these five probes seem to be much lower than would be expected. For example, the average carbon tetrachloride concentration from those five probes is 320 ppmv, while the lowest concentration measured at all the other probes is 840 ppmv at DU-14-VP3 (first quarter FY 2003). In addition, the concentration at Probe 743-18-VP1 at a depth of 21 ft was 117 ppmv, while the concentration at Probe 743-18-VP4, just 6 ft above, was 8,261 ppmv. Similarly, the concentration at Probe DU-14-VP1 at a depth of 17 ft was 221 ppmv, while the concentration at Probe DU-14-VP2, just 5 ft above, was 5,301 ppmv. The concentrations of other VOCs (chloroform, TCE, TCA, and PCE) at these five probes are similarly low.

It is possible that the low concentrations are real, but this is unlikely, given the drastic differences in concentration between neighboring probes and the high mobility of vapor-phase VOCs. The ability to get a sample from five previously unyielding probes is attributed to an increase in the vacuum pressure, which may have caused a leak in the system and diluted the samples. This and other possible explanations are being investigated by the project.

2.2.7 Conclusions and Recommendations

Samples were collected consistently from eight of the 18 Type B vapor probes at the SDA during the four quarters of FY 2003. During the last quarter, samples were obtained from an additional five probes that had previously not yielded a sample because of plugging or other difficulty. The validity of the sample results from these five probes is being investigated because of the seemingly low concentration values. All samples were analyzed with an Innova Model 1314 photoacoustic portable multigas analyzer. A small number of collocated duplicate samples were sent to laboratories for confirmatory analysis. Problems with the SWLO analyses prompted rejection of the data. Significant differences between the Innova and INEEL ECL results for the confirmatory samples from the last two quarters are being investigated.

The conclusions of the Type B vapor probe sampling and analysis are:

- VOC concentrations are steady or decreasing slightly, depending on the location. If the GC/MS results are more accurate than the Innova results for the last two quarters of FY 2003, there is a definite decrease, and it is more significant.
- The results also support information and assumptions used to estimate the original amount of VOCs buried in the SDA as well as burial locations of the VOC waste. This conclusion is independent of the data uncertainty during the last two quarters of FY 2003.
- VOC concentrations from the probes are comparable to those predicted to be in equilibrium with Series 743 sludge. This conclusion also is independent of the data uncertainty during the last two

quarters of FY 2003. However, if the GC/MS data are more accurate, then the data are becoming less comparable to the equilibrium concentrations.

- Some VOC concentrations appear to be seasonally dependent. This is plausible given the volatilization and partitioning dependence on temperature. Further monitoring is necessary to determine trends in release rates and to establish a baseline, which can then be used to validate numerical models, to estimate the persistence of the source, and to define remediation plans both for the VOCs and other contaminants whose remedy may depend on the presence of VOCs. The evidence for this conclusion is less compelling if the Innova data from the last two quarters of FY 2003 are not accurate.
- It may be possible to get samples from probes that previously did not yield a sample. This will not be known until we know why we were able to get first-time samples from five of the probes or if the sampling system has a leak.

Given the preceding conclusions, the following recommendations are offered:

- Continue quarterly monitoring until temporal trends and basis are determined. The length of time will depend on the basis for change and the rate of change.
- Use SMR temperature data at depth to support evaluation of seasonal dependence on concentrations.
- Investigate disparity in Innova and INEEL ECL analytical results to ensure equivalency.
- Determine if the data from probes that yielded a sample for the first time in the fourth quarter of FY 2003 are representative, and determine the cause for why a sample was able to be obtained.

2.3 Carbon-14

2.3.1 Sample Collection Method

The C-14 samples are withdrawn from the probes using a peristaltic pump and collected in 1-L Tedlar bags. Tritium (H-3) samples were originally to be collected using a programmable low-flow air sampler to pull soil gas through a desiccant bed. However, the single probe in SVR-20 that yields a sample requires more vacuum than can be generated by the programmable tritium sampler. To date, some C-14 samples have been taken from the SVR-20 Type B probe, but no tritium samples have been taken.

2.3.2 Sample Schedule

Currently, C-14 samples are collected quarterly from the functioning Type B vapor probes at SVR-12 and SVR-20. The *Field Sampling Plan* (Salomon 2003) calls for quarterly sampling of the SVR-20 probes for tritium, but this has not been possible because there is high resistance to flow through these probes or the soil surrounding the probes.

2.3.3 Analysis Methods

The C-14 samples are analyzed for C-14 specific activity (the C-14 activity per unit mass of total carbon). This requires analysis for total carbon and total C-14 activity in the gas sample. Total carbon is determined by using gas chromatography to measure CO₂ concentration in the sample and by measuring the total sample volume with a 1-L gas syringe. Approximately 12 mL of 0.5 normal NaOH solution is

injected into the bag to absorb the CO₂ in the sample. Then approximately 10 mL of the NaOH solution are recovered from the bag, mixed with a compatible liquid scintillation cocktail, and counted. Actual amounts of solutions used or transferred are determined gravimetrically. Liquid scintillation counting is performed using an ultra-low-level liquid scintillation counter (Wallac Quantalus[®] or PerkinElmer[®] 3170 TR/SL). Typically, 16-hour count times are used for low-level samples such as those from SVR-12. National Institute for Standards and Technology-traceable C-14 standards (as sodium carbonate) prepared with 0.5 normal NaOH are used to evaluate the counting efficiency.

2.3.4 Results

The C-14 results for the functioning Type B soil vapor probes at SVR-12 and SVR-20 are presented in Table 2-7.

Table 2-7. Specific activity of carbon-14 (pCi C-14/g carbon) from soil-vault-row Type B vapor probes.

Date	SVR-12-1-VP1	SVR-12-1-VP2	SVR-12-1-VP3	SVR-12-2-VP1	SVR-12-2-VP2	SVR-12-2-VP3	SVR-12-3-VP1	SVR-12-3-VP2	SVR-12-3-VP3	SVR-20-5-VP3
11/15/01	—	—	—	—	—	—	—	—	—	83,000
12/03/01	3,300	3,270	8,410	2,700	3,500	—	2,900	3,000	8,200	—
2/20/02	2,100	450	—	1,400	—	—	2,000	1,500	16,000	28,000
5/23/02	990	450	2,800	1,400	840	630	1,200	1,600	370	31,000
8/13/02	1,200	990	1,600	1,300	1,000	380	2,200	1,200	480	—
8/23/02	—	1,200	—	—	—	—	—	—	—	37,000
11/13/02	710	—	<MDA ^a	1,500	590	<MDA	1,100	680	<MDA	24,000
2/3/03	880	560	<MDA	970	—	480	1,100	680	<MDA	—
5/15/03	710	680	230	820	550	280	480	680	110	—
11/5/03	—	480	—	—	—	—	—	—	—	41,000 ^b

— = indicates that no sample was taken on that date.

MDA = minimum detectable activity

a. Relative uncertainty >33%. The relative uncertainty of the other results is typically 5–10%. Also, the CO₂ concentrations in these samples are relatively low.

b. In the analytical report, SVR-20-5-VP3 probe results apparently were switched with the SVR-12-1-VP3 results. The value reported here is considered to be the correct value for the sample.

2.3.5 Discussion

Routine sampling of soil gas for C-14 began in FY 2002. The Tedlar bag sampling method was still in development during the first half of FY 2002, and the results are generally qualified because of limitations of the counting instrumentation. The first sample set was used to evaluate the relative performance of the Wallac Quantalus and the Beckman LS-6000 liquid scintillation counters. The Wallac was expected to have considerably better low-level counting performance and, in fact, is required for sufficiently sensitive analysis of C-14 activity. The second sample set (collected February 20, 2002) was not analyzed with the Wallac, but the Wallac was used for subsequent sample sets.

The results for C-14 analysis of SVR-12 samples indicate that the C-14-specific activity is substantially elevated (on the order of 100 times) above the naturally occurring level of 6.5 pCi C-14/g carbon.

The results for C-14 analysis of samples from the SVR-20-5-VP3 Type B probe are consistent with results for samples taken from the GSP-1 soil vapor ports at SVR-20 (Olson et al. 2003). The C-14-specific activity at SVR-20, near the activated beryllium, is generally a factor of 10 to 100 times greater than the specific activity measured near the activated stainless steel at SVR-12. This is consistent with the source-term model for these wasteforms—the fractional rate of C-14 release from activated steel is expected to be much less than from activated beryllium, and the C-14 concentration within activated steel is much lower than in activated beryllium.

2.3.6 Conclusions and Recommendations

Although the specific activity of C-14 in CO₂ from soil gas near activated steel is elevated by approximately two orders of magnitude relative to natural levels, the C-14 activity contained in a typical 1-L bag sample is on the order of 1 pCi. Low-level liquid scintillation counting methods are required for C-14 analysis of the SVR-12 samples. The C-14 bag method appears to be well suited for characterizing C-14 in SDA soil gas, provided that an ultra-low-level liquid scintillation counter is used for C-14 assay. The method development work should be documented in an engineering design file, which would serve as the basis for writing a standard procedure for routine work. As expected, the concentration of C-14 in soil near activated steel is much less than the concentration observed near activated beryllium. The relatively low concentration of tritium at SVR-12 confirms that the SVR-12 location is not affected by tritium migration from other sources (i.e., activated beryllium) and suggests that the location is not affected by C-14 from buried beryllium. If possible, some additional soil gas samples should be taken at other SDA locations to confirm that the SVR-12 C-14 results are representative of buried activated steel rather than of broadly distributed C-14 contamination.

3. LYSIMETER

3.1 Introduction

Eighteen drive-point soil-water solution samplers, referred to as lysimeters, were designed by the INEEL; constructed by Northeast Manufacturing of Meridian, Idaho; and installed using the INEEL sonic drill. The lysimeter design and operation are described in *OU 7-13/14 Integrated Probing Project Type B Probes Lysimeter Probe Design* (Clark 2001a). Lysimeters can be used to collect soil moisture solution samples (pore water) from either saturated or unsaturated sediment. The lysimeters have a semipermeable stainless steel membrane that allows water to move through but restricts air movement. Soil water is withdrawn from the surrounding soil by applying a lower pressure in the lysimeter than in the soil for a period to collect water in a chamber. Once water has accumulated in the lysimeter, a positive pressure is applied to push the water to land surface, where it is placed in sampling bottles and submitted to laboratories for analyses. Difficulty has been experienced in obtaining lysimeter samples, and installation of the lysimeters with the sonic drill rig is suspected of causing mechanical problems. The lysimeters have been redesigned to avoid installation damage and to improve sampling success.

3.2 Probe Development

Instrument development was conducted on the Type B suction lysimeter probe design to protect the inner workings during installation and to allow the porous stainless steel membrane to be rewetted following installation. A new design was conceived, and prototypes were constructed and then tested in both the laboratory and field. The improved probe design, named the INEEL Geologic and Environmental Probe System, incorporates a universal probe tip and casing that are driven into the subsurface, and then an instrument insert is placed into the probe to complete the instrument. The two-piece design avoids placing the instrument's inner workings under sonic installation stresses, while allowing the porous membrane to be rewetted following installation. An additional advantage of this design is that different instrument inserts can be placed within the probe to obtain other measurements important for characterizing water and contaminant transport within the waste. This design allows the probe to be used not only for soil-water sampling (lysimeter) but also for gas sampling, monitoring of soil-water potential, and monitoring of other geophysical properties (e.g., water content, spectral, and clay distribution) with the insertion of other geophysical instruments. This enhanced design combines the Type A and B probes to allow all of the same measurements with one universal probe. Forty-two new lysimeters have been fabricated and are scheduled for installation in FY 2004.

3.3 Analytical Data

One waste-zone lysimeter yielded water during FY 2003. Approximately 10 mL of soil moisture was collected from Probe 741-08-L1 on September 8, 2003, and analyzed for gamma-emitting radionuclides. There were no positive detections. The sample ID is IPL135013A. There was inadequate volume to perform other radiological analyses. Historically, Pu-239/240 has been detected in soil moisture from this lysimeter in November 2001 and April 2002. Neptunium-237 has been detected in moisture samples from Probe 741-08-L1 in April 2002.

4. TENSIO METER

4.1 Introduction

In 2001, 66 drive-point tensiometers were installed in surficial sediment in the SDA using a sonic drill. The tensiometers were installed at three target depths (at the top of the waste, at the midpoint within the waste, and in sediment beneath the waste) to determine if sediment or waste was saturated, to calculate hydraulic gradients, and to monitor infiltration and drainage through waste.

4.2 Direct-Push Tensiometers

Direct-push tensiometers are instruments that yield water potential and soil gas pressure in the surrounding material. The direct-push tensiometer has a drive point and a sealed porous stainless steel chamber filled with water that is installed at a specified depth. This chamber is connected by lines to a second upper water chamber, and the upper chamber, in turn, has two lines that extend to land surface for refilling with water. The lines in the lower chamber have valves located immediately above the lower water chamber, and when closed, these valves isolate the upper chamber from the water in the water lines. When open, the lines can be used to refill the lower chamber from the upper chamber reservoir. Two transducers are located in the direct-push tensiometer. An absolute pressure transducer in hydraulic connection with the lower chamber senses the soil-water pressure in the surrounding sediment through the porous stainless steel membrane. A second pressure transducer, located above the lower transducer, measures the gas pressure in the soil. A third line extends to land surface that, when combined with the other lines and valves, allows the sensors to be tested relative to a reference pressure in the field.

In operation, a measured volume of water is placed in the upper water chamber and then the lower water chamber by opening a combination of valves. The lower chamber is filled with water from the upper water chamber and then sealed. Water in the porous stainless steel cup then moves into or out of the formation in response to soil-water changes in the soil matrix. Water, moving from the initial atmospheric pressure in the porous cup to a subatmospheric (negative) pressure in the soil (unsaturated conditions), creates a partial vacuum in the porous cup that is sensed by the lower pressure transducer. Tensiometer design and operations are fully described in *OU 7-13/14 Integrated Probing Project OU 7-13/14 Tensiometer Probe Design* (Grover 2001).

The water potential data from these advanced tensiometers are used to track changes in moisture over time and to describe relative moisture conditions at each location. Under fully saturated conditions, water is at hydrostatic pressures greater than atmospheric pressure, and water potential is positive. Under unsaturated conditions, capillary and adsorptive forces hold water in the soil matrix. In this unsaturated state, water potential is negative by convention because the hydrostatic pressures are less than atmospheric pressures. For a homogeneous medium, the more negative the water potential, the dryer the medium; decreasing water potentials indicate decreasing water content, and conversely, increasing water potentials indicate increasing water content.

4.3 Installation

Direct-push tensiometers were installed at the SDA in fall of 2001 at three target depths: at the top of the waste, at the midpoint within the waste, and in sediment beneath the waste. Probes were installed by driving them with drill-rig down pressure until consolidated sediment was encountered at a depth of about 2 ft. Then, the probe was sonically pushed to the specified depth. Locations of the tensiometers are shown in Figure A-1.

4.4 Data Collection

Pressure transducers are connected to a datalogger (Campbell Scientific, Inc.) for continuous monitoring and data storage. The data are queried on a 2-hour interval, and data are transmitted to a computer at the RWMC for retrieval and analysis. The data are posted on a shared directory and imported into Excel spreadsheets for evaluation.

In FY 2003, system checks were performed on all dataloggers and instruments. Selected transducers were individually interrogated to check readings and determine functionality. As a result of these checks, all datalogger enclosures were configured to

- Address problems of instrument communications
- Reposition batteries to prevent acid damage in the event of a leak
- Standardize the configuration so all boxes were identical in hardware and software
- Revise software to make boxes field-configurable
- Add input to measure solar power output voltage
- Add connectors to remove problems with spliced wires and facilitate field replacement.

Five multiplexers also were built and added to the system as part of addressing these problems. A new set of design files for the instruments and datalogger network was completed (EDF-3612) and entered into the Electronic Data Management System.

4.5 Use and Accuracy of the Data

Data from the tensiometers are used to calculate soil-water potential. Water potential is a means of measuring the relative energy state of water to evaluate the status and movement of water. The sensor measurement from the soil gas pressure (upper sensor) is subtracted from the soil-water potential sensor (absolute, lower sensor) to calculate the soil-water potential relative to atmospheric pressure (standard measurement technique). In order for the lower soil-water potential (absolute) sensor to work, sufficient water must be held in the lower reservoir, and the porous membrane must remain saturated to prevent air entry through the membrane. If the membrane is not saturated, the sensor will track atmospheric pressure.

4.5.1 Laboratory Calibration

All the sensors (15-psia Sensotec pressure transducers) have undergone the initial INEEL Standards and Calibration Laboratory calibration with the required specification that the sensors are within $\pm 2\%$ of full scale or ± 5 cm of water pressure over the range of measurements.

4.5.2 Field Calibration

Once the tensiometers were installed, the contained sensors could not be removed for laboratory calibration. The sonic insertion technique placed the pressure sensors under moderate-to-very-high stresses from the sonic insertion technique, and the vibration from the sonic drilling had the potential to alter the calibration. Using the third line that extended from the sensors to land surface, the sensors were field calibrated to a reference pressure in the field in FY 2003. These new calibrations may be applied to the calculated soil-water potential (relative to atmospheric pressure) for increased accuracy.

4.6 Results and Discussion

Eight of the direct-push tensiometers provided calculated soil-water potential (relative to atmospheric pressures) responses over an extended period. These responses are shown in Figures 4-1, 4-2, 4-3, and 4-4. Figure 4-1 will be discussed in detail to better understand the tensiometer responses, but discussion of the remainder of the figures will focus on the representative data.

The tensiometer data shown in Figure 4-1 are from the 19.9-ft probe in Cluster 741-08 and the 18.5-ft probe in Cluster 743-03. The initial data from both of these instruments are near zero because the tensiometer was not yet functioning. In March (Probe 741-08-T3) and April (Probe 743-03-T3) 2002, water was added to the porous cup of the tensiometer, and the water potential began to drop. Field maintenance in April 2002 caused a steep rise to zero at Probe 743-03-T3 but again began to drop as the tensiometer continued equilibrating with the surrounding soil. When the steep drop in water potentials began to level off (i.e., late April at Probe 743-03-T3), the tensiometers were in equilibrium with the soil water and collecting representative data. Probe 741-08-T3 showed approximately -90 cm water, and Probe 743-03-T3 indicated approximately -350 cm water. Both tensiometers then show a slight increase in water potentials that reaches a maximum in December 2002 and then decrease until late spring 2003. This increase and decrease in water potentials reflects minor infiltration and drainage over that period. The sudden rise in water potentials to zero in May 2003 at Probe 743-03-T3 was caused by field maintenance, but the water potential values that follow show the tensiometer reequilibrated with the soil water by August 2003.

The water potentials at Probe 743-03-T3 after August 2003 are approximately 30 cm lower than the May 2003 values and show greater variation. It is possible the transducer in Probe 743-03-T3 is no longer stable or needs to be recalibrated and should be field checked. A field check also should be performed at Probe 741-08-T3. The output data from Probes 741-08-T2 (10.6 ft) and 741-08-T3 (19.9 ft) were switched in the datalogger in September 2003. The depth (19.9 ft) listed in Figure 4-1 for Probe 741-08-T3 represents the depth before the wiring was switched. The depth will be corrected to 10.6 ft (Probe 741-08-T2) if the field check indicates the switch was necessary.

Both Probes 741-08-03 (19.9 ft) and 743-03-T3 (18.5 ft) are located below the waste, and the minor infiltration seen in fall 2002 represents recharge that probably moved through the waste. The two probes indicate different water potentials (approximately -90 cm water versus -350 cm water), and this difference may reflect a different lithology or different moisture conditions between these two separate cluster areas. A soil moisture probe (Probe 743-03-237 [19.1 ft]) located within 3 ft of the tensiometer probe (Probe 743-03-T3 [18.5 ft]) indicates volumetric soil moisture contents of approximately 27%. This is reasonable moisture content for silt at -350 cm water. A volumetric moisture content of approximately 22 %, measured at soil moisture Probe 741-08-266 (20.0 ft) within 5 ft of tensiometer Probe 741-08-T3 (19.9 ft), would not be realistic for a silt at approximately -90 cm water but would be reasonable in a sand. It is also possible the two clusters represent wetter and drier areas within the SDA, based on the tensiometer data.

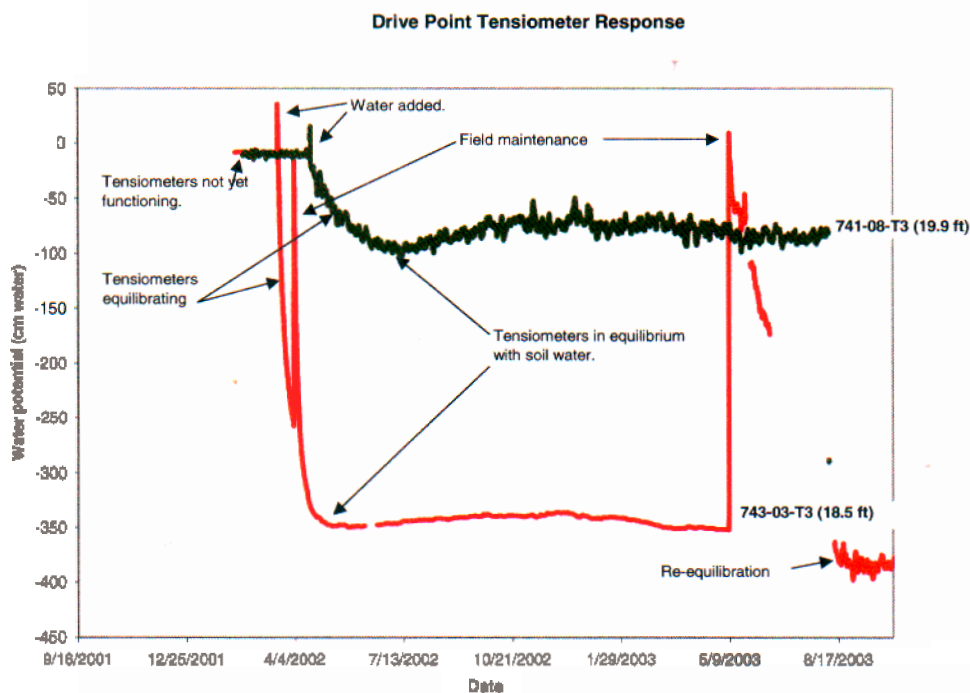


Figure 4-1. Calculated soil-water potential (relative to atmospheric) data from two probes at Clusters 741-08 and 743-03.

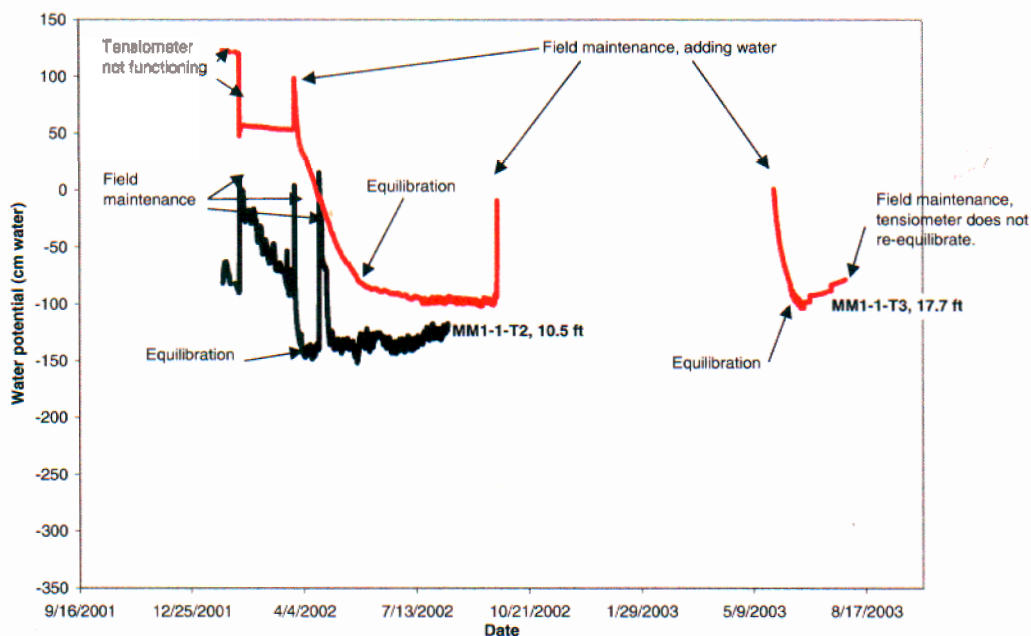


Figure 4-2. Calculated soil-water potential (relative to atmospheric) data from two locations at Cluster MM1-1.

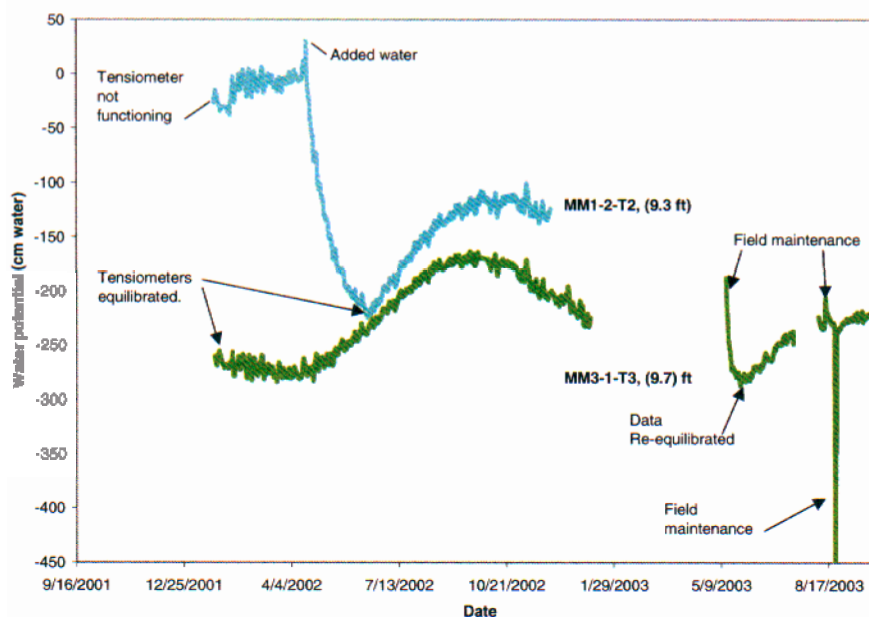


Figure 4-3. Calculated soil-water potential (relative to atmospheric) data from selected locations at Clusters MM1-2 and MM3-1.

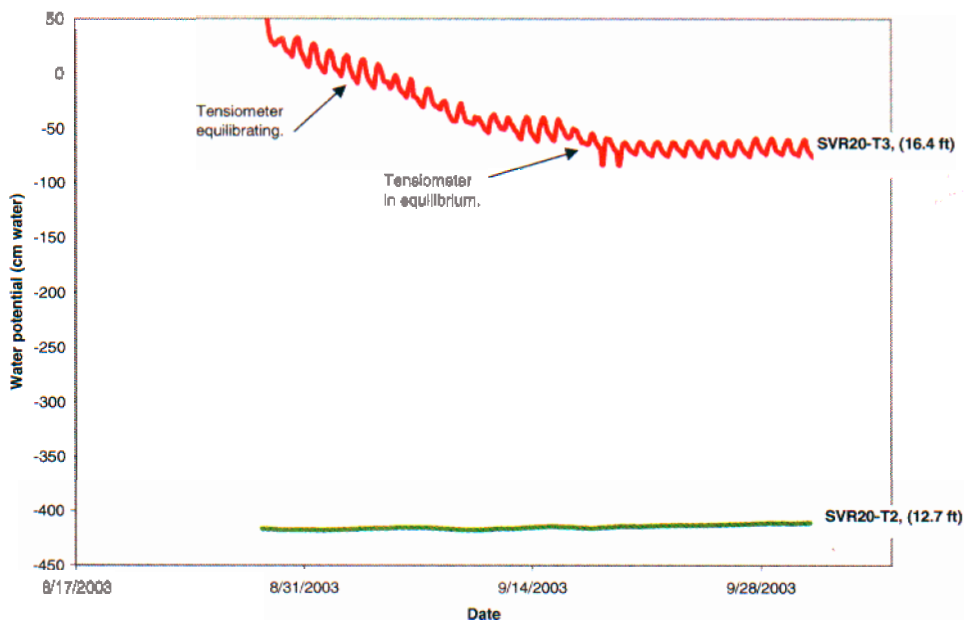


Figure 4-4. Calculated soil-water potential (relative to atmospheric) data from two locations at SVR-20.

Water potential data from two of the Cluster MM-1 tensiometer probes are shown in Figure 4-2. These tensiometer probes are located near the borrow pit, alongside the main east-west road through the SDA. Equilibrated water potentials from tensiometer Probes MM1-1-T2 (10.5 ft) and MM1-1-T3 (17.7 ft) show near-constant water potentials over the monitoring period. Probe MM1-1-T3 (17.7 ft) shows a rise in water potentials in July 2003 that is consistent with infiltration but could also be loss of water from the tensiometer cup. The data were interrupted by field maintenance and did not reequilibrate.

In contrast, tensiometer Probes MM1-2-T2 (9.3 ft) and MM3-1-T3 (9.7 ft) indicate infiltration occurred from late spring to fall of 2002, and drainage followed into December 2002 (see Figure 4-3). After a data gap, Probe MM3-1-T3 again shows infiltration from late spring to fall of 2003. Soil moisture Probes MM1-2-238 (6 ft) and MM3-1-242 (9.7 ft) (see Appendix C), located near these tensiometers (MM1-2-T2 [9.3 ft] and MM3-1-T3 [9.7 ft], respectively), also indicate infiltration occurred during these timeframes. The timing of infiltration may correspond with 0.74 in. of precipitation over a 4-day period in mid-April 2002 and 0.61 in. of precipitation over a 5-day period in April 2003 at the RWMC (NOAA 2004). Infiltration at these locations occurred in spite of less-than-average annual precipitation during the monitoring period (i.e., 4.53 in. in 2002 and 3.91 in. in 2003 [see Section 1.5], compared to an 8.71-in. annual average at the Central Facilities Area [Clawson, Start, and Ricks 1989]).

Approximately 1 month of water potential data for tensiometer Probes SVR-20-T2 (12.7 ft) and SVR-20-T3 (16.4 ft) is shown in Figure 4-4. Although one should be careful comparing water potential from different types of soil to each other, large differences in values can imply a degree of wetness in a general sense. The water potentials indicate that the deeper 16.4-ft tensiometer is very wet at approximately -50 cm of water and that the shallower 12.7-ft depth is drier at approximately -425 cm of water.

4.6.1 Instrument Performance

The majority of the tensiometers did not provide useable water potential data for 2002 and 2003. The tensiometer design is complex to ensure no radiological pathway to the surface when instrumentation is located in or near waste. However, the complexity of the design also provided many avenues for failure (e.g., valve failure or transducers that were not replaceable). The use of sonic drilling during installation also may have increased the potential for dewatering the porous stainless steel and damaging the instrument (e.g., loosening fittings, kinking tubing, and breaking seals).

Only eight out of 66 direct-push tensiometers installed in the SDA provided water potential data needed to characterize moisture movement through surficial sediment and waste. Table 4-1 lists the tensiometers, the working status of the transducers, and a recommendation to continue or discontinue the use of each direct-push tensiometer in the monitoring network. Troubleshooting is recommended for tensiometers that show potential for good performance. Recommendations are made to remove tensiometers from the monitoring network if the tensiometers have failed or if the tensiometers are located in soil that is too dry to allow continuous operation (such as the shallowest tensiometers). Plots of the raw data and a more detailed evaluation of the operability of the individual direct-push tensiometers are presented in Appendix D.

Table 4-1. Summary of monitoring recommendations for direct push tensiometers.

Cluster	Tensiometer	Depth (ft)	Transducer Status		Recommendation
			Soil Gas	Soil Water	
DU-08	DU-08-T1	5.3	Failed	Failed	Discontinue
	DU-08-T2	10.2	Working	Works sporadically	Continue
	DU-08-T3	16.4	Working	Failed	Discontinue
DU-10	DU-10-T1	4.0	Working	Failed	Discontinue
	DU-10-T2	6.7	Working	Working	Continue
	DU-10-T3	9.1	Working	Working	Continue
DU-14	DU-14-T1	3.7	Failed	Failed	Discontinue
	DU-14-T2	9.0	Failed	Failed	Discontinue
	DU-14-T3	15.3	Failed	Failed	Discontinue
743-03	743-03-T1	5.3	Worked previously	Some response to adding water	Continue
	743-03-T2	11.2	Failed	Failed	Discontinue
	743-03-T3	18.5	Some response	Working	Continue
743-08	743-08-T1	5.6	Working	May be working	Continue
	743-08-T2	13.0	Working	Some response	Continue
	743-08-T3	22.4	Failed	Failed	Discontinue
743-18	743-18-T1	5.5	Working	Working	Continue
	743-18-T2	14.9	Working	Failed	Discontinue
	743-18-T3	9.2	Working	Failed	Discontinue
741-08	741-08-T1	3.6	Working	Failed	Discontinue, too shallow
	741-08-T2	10.6	Works	Some response	Continue
	741-08-T3	19.9	Works	Some response	Continue
SVR-12	SVR12-T1	3.6	Works	Failed	Discontinue
	SVR12-T2	8.4	Works	Some response	Continue
	SVR12-T3	10.8	Works	Failed	Discontinue
SVR-20	SVR20-T1	8.3	Works	Some response	Continue
	SVR20-T2	12.7	Works	Works	Continue
	SVR20-T3	16.4	Works	Works	Continue

Table 4-1. (continued).

Cluster	Tensiometer	Depth (ft)	Transducer Status		Recommendation
			Soil Gas	Soil Water	
MM1-1	MM1-1-T1	5.6	Works	Works	Continue
	MM1-1-T2	10.5	Works	Failed	Discontinue
	MM1-1-T3	17.7	Some response	Some response	Continue
MM1-2	MM1-2-T1	5.6	Works	Failed	Discontinue
	MM1-2-T2	9.3	Works	Some response	Continue
	MM1-2-T3	14.0	Works	Some response	Continue
MM1-3	MM1-3-T1	5.1	Works	Some response	Continue
	MM1-3-T2	8.4	Works	Some response	Continue
	MM1-3-T3	11.7	Failed	Failed	Discontinue
MM2-1	MM2-1-T1	6.7	Some response	Failed	Discontinue
	MM2-1-T2	11.9	Some response	Some response	Continue
	MM2-1-T3	16.0	Some response	Some response	Continue
MM2-2	MM2-2-T1	5.0	Works	Some response	Continue
	MM2-2-T2	8.6	Works	Failed	Discontinue
	MM2-2-T3	9.2	Failed	Failed	Discontinue
MM2-3	MM2-3-T1	3.8	Works	Failed	Discontinue
	MM2-3-T2	5.1	Works	Failed	Discontinue
	MM2-3-T3	6.6	Works	Failed	Discontinue
MM3-1	MM3-1-T1	4.9	Failed	Failed	Discontinue
	MM3-1-T2	7.1	Works	Failed	Discontinue
	MM3-1-T3	9.7	Works	Works	Continue
MM3-2	MM3-2-T1	5.0	Works	Failed	Discontinue
	MM3-2-T2	6.6	Works	Some response	Continue
	MM3-2-T3	8.4	Works	Failed	Discontinue
MM3-3	MM3-3-T1	14.0	Works	Some response	Continue
	MM3-3-T2	4.6	Works	Some response	Continue
	MM3-3-T3	17.0	Failed	Failed	Discontinue
MM4-1	MM4-1-T1	5.7	Works	Some response	Continue
	MM4-1-T2	14.9	Works	Some response	Continue
	MM4-1-T3	18.5	Works	Some response	Continue

Table 4-1. (continued).

Cluster	Tensiometer	Depth (ft)	Transducer Status		Recommendation
			Soil Gas	Soil Water	
MM4-2	MM4-2-T1	4.9	Works	Failed	Discontinue
	MM4-2-T2	11.4	Failed	Some response	Continue
	MM4-2-T3	15.8	Failed	Failed	Discontinue
MM4-3	MM4-3-T1	3.6	Works	Failed	Discontinue
	MM4-3-T2	8.2	Works	Failed	Discontinue
	MM4-3-T3	9.5	Works	Some response	Continue
MM4-5	MM4-5-T1	4.1	Failed	Failed	Discontinue
	MM4-5-T2	9.7	Some response	Failed	Discontinue
	MM4-5-T3	13.5	Failed	May be working	Continue

4.7 Conclusions and Recommendations

Continuous water potential data from four locations in the SDA indicate that infiltration occurs through surficial sediment and through waste despite less-than-average precipitation during the last 2 years. The lack of working tensiometers over a depth profile prevents use of water potential data for hydraulic gradients or estimates of infiltration rates.

It is recommended that the tensiometers be monitored through FY 2004 to track infiltration and drainage from the spring 2004 snowmelt. If the performance of the direct-push tensiometers does not improve, it is further recommended that consideration be given to halting the collection of the direct-push tensiometer data at the end of FY 2004.

